ASSESSMENT OF THE USE OF SEAT BELTS IN BUSES BASED ON RECENT ROAD TRAFFIC ACCIDENTS IN SPAIN

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ABSTRACT

The most important topic in the field of passive safety of buses and coaches nowadays is the future compulsory use of seat belts.
The objective of the study performed by IDIADA AUTOMOTIVE TECHNOLOGY SA and CENTRO ZARAGOZA is to make an important contribution to the existing technical data about this subject.
This paper is based on the in-depth analysis of recent road traffic accidents where buses were involved.
The first step is the accident reconstruction. A complete injury report including description and causes of occupant injuries is the basis for the correlation of a computer simulation model.
Experience in the development of coach seats equipped with seat belts enables the preparation of a comparative model. The hypothesis that the consequences of the accident could have been less severe if the occupants of the bus had worn a seat belt can be evaluated. The conclusions will help the legislators make the right decision.

INTRODUCTION

The *Dirección General de Tráfico* (DGT), Spain's road traffic authority, awarded IDIADA AUTOMOTIVE TECHNOLOGY SA with a two year contract to study road traffic accidents involving buses and coaches.
One of the purposes of the study is making recommendations on possible passive safety enhancements to this type of vehicle.
The first bus accident whose reconstruction was undertaken by IDIADA AUTOMOTIVE TECHNOLOGY SA occurred on October 6th 2000 at 1:30 in the province of Navarra. A single-decker coach had a frontal impact against an articulated lorry, which had previously rolled over on the motorway A-15. 3 people died, 19 people were seriously injured and 27 people received less severe injuries. The coach had been manufactured during the year 2000 and it was in perfect conditions, but it failed to protect the occupants in a frontal collision.
Two previous accidents had been analysed by CENTRO ZARAGOZA. The first one, a rollover, occurred on September 19th 1999 on the motorway N-II, in the province of Zaragoza. 29 people died and 24 were seriously injured. The second was a crash between a school bus and a truck carrying livestock on July 6th 2000 on the road N-122, in the province of Soria. 28 young people died.
IDIADA AUTOMOTIVE TECHNOLOGY SA and CENTRO ZARAGOZA decided to use the results of the in-depth accident reconstruction of these cases as a basis for a study on the possible benefits of the use of seat belts in buses.

CASE 1: ZARAGOZA

Accident Reconstruction

The bus consists of a chassis SCANIA K113 CLB and a body CAETANO Delta. There are 57 seating positions on it, including the driver seat and the guide seat at the front left side of the bus. The kerb weight of the bus is 13300 kg and it has two axles. The front axle is single and the rear one is double. Figure 1 shows a photograph and a drawing of the vehicle.
The sequence of the accident is shown in Figure 2.
The bus was driving at noon on the motorway at a speed of 106 km/h. It was raining. At a certain moment, the skidding of the rear axle started. From that moment on, the bus reeled from side to side, eventually spinning around 180 degrees, completing this turn outside the road. At the place where the bus left the road, there was no retention barrier. The bus left the road and rolled over. Right at that place where the bus fell, there was a small watercourse, with a depth of water of one meter and a half at that time.

Figure 1. Photograph and drawing of the vehicle.

Figure 2. Sequence of the accident.

Injuries

The number of occupants was 52, including the driver and the guide. All of them were ejected from their seats and most of them were thrown out of the bus, fell in the watercourse and died.
The seating positions in the coach are shown in Figure 3.

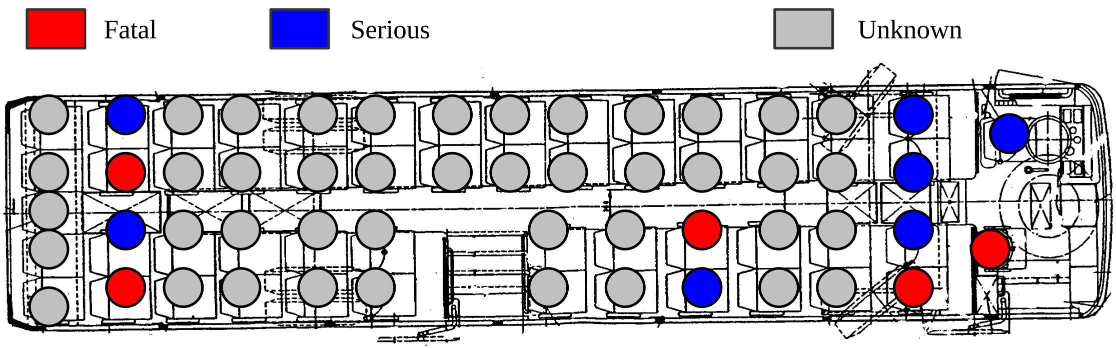


Figure 3. Severity of occupant injuries.

The occupants whose position before the accident is known are represented in different colours. The persons who occupied those positions painted in red, died. The occupants of the seating positions coloured in blue were considered seriously injured by the police.
This case is a typical situation of occupant ejection in a rollover accident. The vehicle kinematics during the rollover has not been precisely determined. The position of most of the passengers before and after the accident is unknown. Most passengers drowned in the watercourse. An occupant simulation was not carried out in this case. It had been difficult to fix the boundary conditions and validate any possible results.

CASE 2: SORIA

Accident Reconstruction

The bus consists of a chassis MAN 13230 HOCL and a body UGARTE CX Elite. There are 45 seating positions, including the driver seat and the guide seat at the front left side of the bus. The kerb weight of the bus is 13600 kg and it has two axles. The front axle is single and the rear one is double. Two photographs and a drawing of the bus are shown in Figure 4.
The truck is a VOLVO F12 having a kerb weight of 17100 kg, four axles and carrying livestock. A photograph and a drawing of the truck are shown in Figure 5.

Figure 4. Photographs and drawing of the bus.

Figure 5. Photograph and drawing of the truck.

The sequence of the accident is shown in Figure 6. The truck was driving towards a curve to the right on a national road at 81 km/h. The truck invaded the opposite lane and collided with the bus, driving in its lane at 99 km/h. During the collision the left side of the coach was extremely deformed. After the impact, the truck followed a straight trajectory through the opposite lane, it crossed the barrier and left the road. The bus left the road on its right side moving laterally.

Injuries

The seating positions in the coach are shown in Figure 7. The persons who occupied those positions painted in red, died. The occupants of the seating positions coloured in blue were seriously injured, according to the subjective evaluation of the police. Six seats were unoccupied.

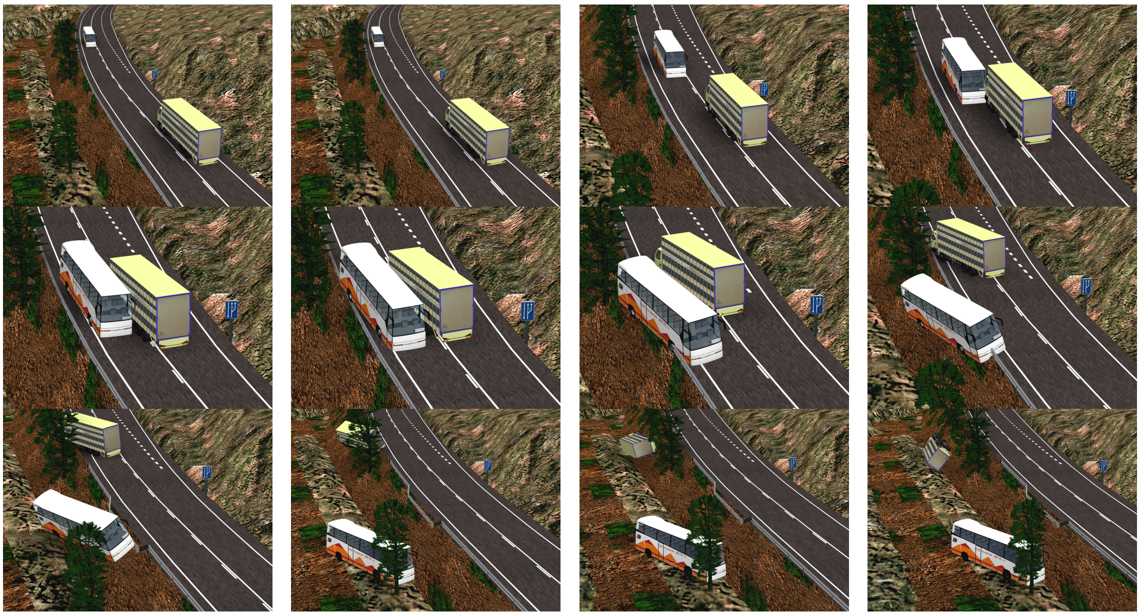


Figure 6. Sequence of the accident.

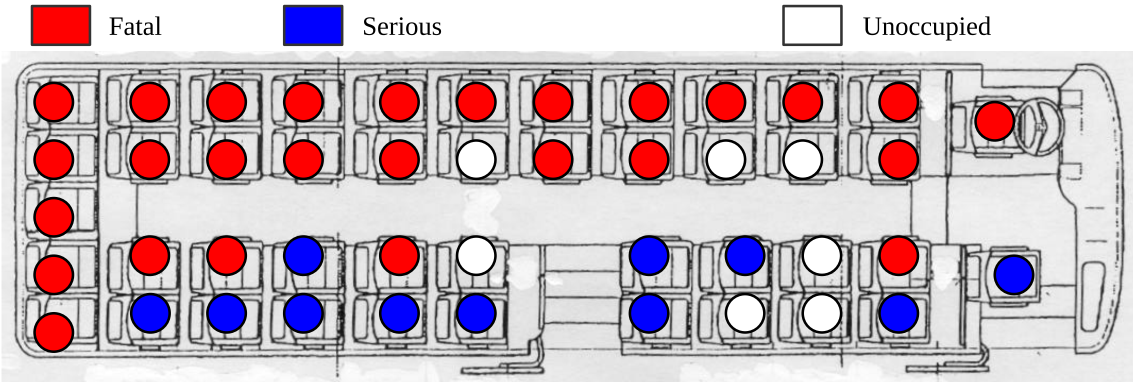


Figure 7. Severity of occupant injuries.

All passengers sitting at the left side of the coach died. The occupants would not benefit from wearing a seat belt. The photographs of the vehicle after the accident in Figure 8 show the deformations at this area.
An area at the right side of the vehicle was selected for an in-depth analysis.

Figure 8. Photographs of the left side of the vehicle.

Occupant Simulation

The software used to simulate the occupant dynamics is MADYMO®. Although it was a school bus, its passengers were aged between 14 and 16 years. Biomechanically they are considered as adult occupants. The standard mathematical models of the dummy Hybrid III 50th percentile male are used.

At the right side area, a first simulation on the selected seating positions was made to compare with the real accident. In this case, the occupants were unrestrained. A second simulation was made with a three-point safety belt on each seating position. The properties of that seat belt were taken from an existing model of bus seat. The simulation results for this area are shown as animations in Figure 9.

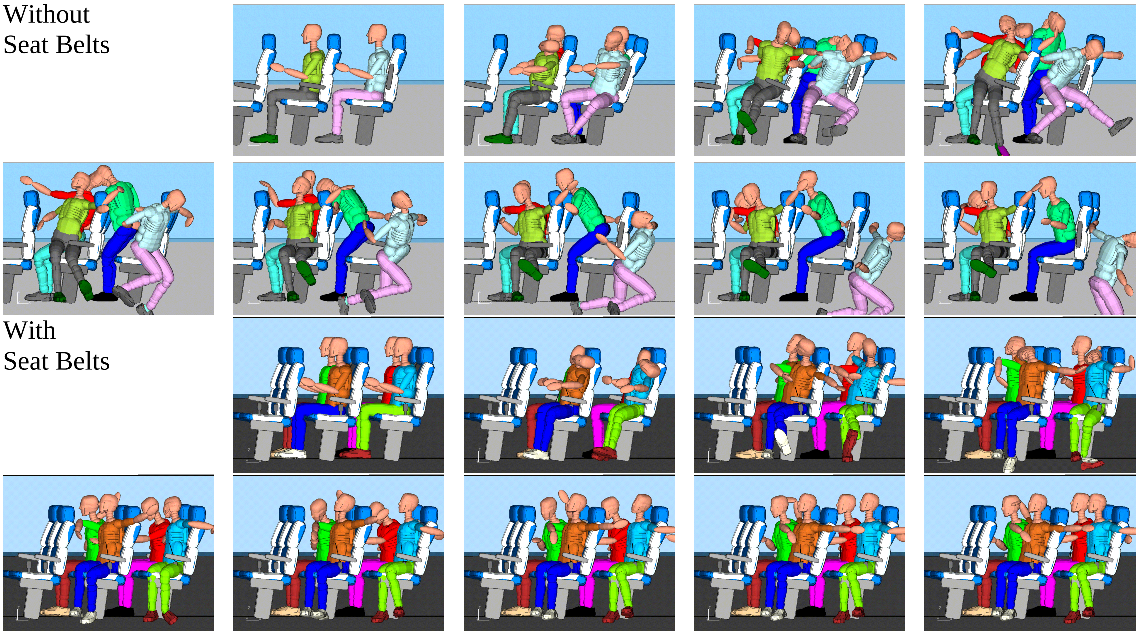


Figure 9. MADYMO® animations for the right-side area.

The occupant simulation without seatbelt considers that the armrest is down in the first row. The ejection is avoided but the armrest produces serious abdominal injuries. At the second row the armrest is folded up and the occupant is ejected to the left. This is the case producing fatal injuries to the occupants sitting on the central positions at the right side of the coach. With three-point seat belts, there is no ejection and the position of the armrests has almost no influence on the results.

CASE 3: NAVARRA

Accident Reconstruction

The IDIADA AT Accident Analysis team is using PC-CRASH® software for accident reconstruction. Figures 10 and 11 show the photographs of the two vehicles involved in the accident and the models used in PC-CRASH®.

Figure 10. Photographs and model of the bus.

The bus consists of a MERCEDES BENZ O-404RH chassis and a body NOGE Touring. There are 52 seating positions, including the driver seat and one seat for a guide at the front left side of the bus. The model for the passenger seats is FAINSA America. The kerb weight of the bus is 13640 kg and it has two axles. The front axle is single and the rear one is double.

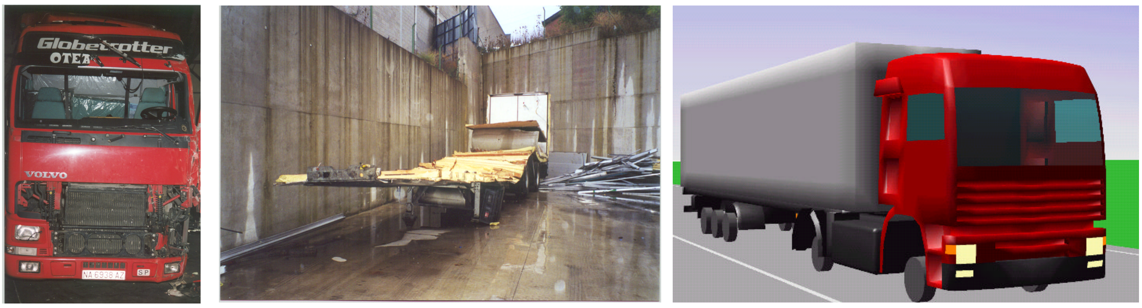


Figure 11. Photographs and model of the articulated lorry.

The lorry consists of a VOLVO FH12 tractor and a LAMBERET LVFS semitrailer. The tractor has a single front axle and a double rear axle and its kerb weight is 6300 kg. The semitrailer has three single axles with a kerb weight of 8500 kg. It was a refrigerator truck carrying tinned food and the weight of the load was calculated to be 2000 kg.

The sequence of events is shown in Figure 12. The articulated lorry was driving at 96 km/h on the motorway when it started an overtaking manoeuvre. While changing to the left lane it went out of the asphalt. The driver tried to correct its way but the lorry rolled over on its left side while the driver was jumping out of the tractor cabin. The overtaken truck stopped from 70 km/h on the right lane and turned the warning lights on. The articulated lorry was lying on its left side across both lanes of the motorway. The distance between the two trucks was 50 meters when stopped. Some seconds after, the single-decker coach was driving towards that point at 105 km/h. The driver saw the truck stopped on the right lane but he did not reduce the speed of the bus. Instead, he decided to overtake that truck at cruising speed. While driving on the left lane, he was making signals with the full-beam headlights. He noticed the obstacle at a distance between 40 and 50 m to the overturned lorry and braked. The bus crashed against the underbody structure of the semitrailer. The impact speed was 70 km/h.

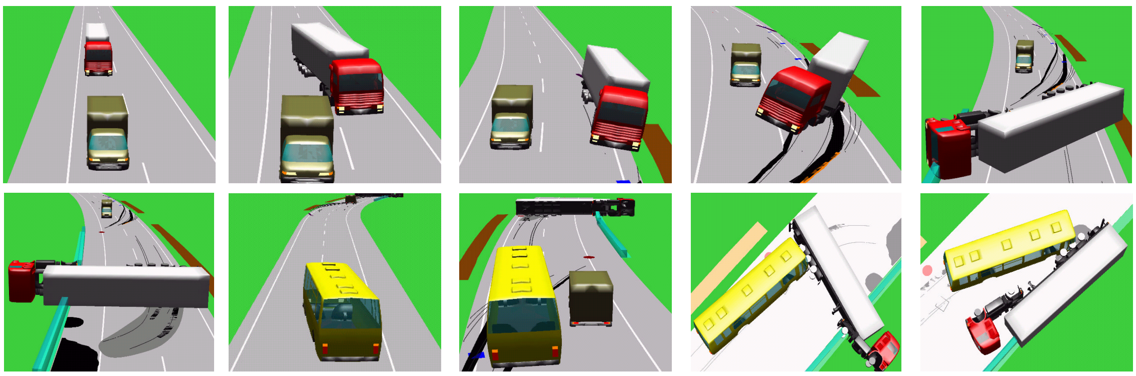


Figure 12. Sequence of accident events from PC-CRASH® animation.

Injuries

The seating positions in the coach are shown in Figure 13. The persons who occupied those positions painted in red, died. The occupants of the seating positions coloured in blue were seriously injured, according to the subjective evaluation of the police. The passengers of those seats painted in yellow were considered slightly injured by the police. There were only two unoccupied seats left in the bus, apart from the guide seat.

The classification of injuries according to the Injury Severity Score (ISS) and the Maximum Abbreviated Injury Scale (MAIS) is represented in Figure 14.

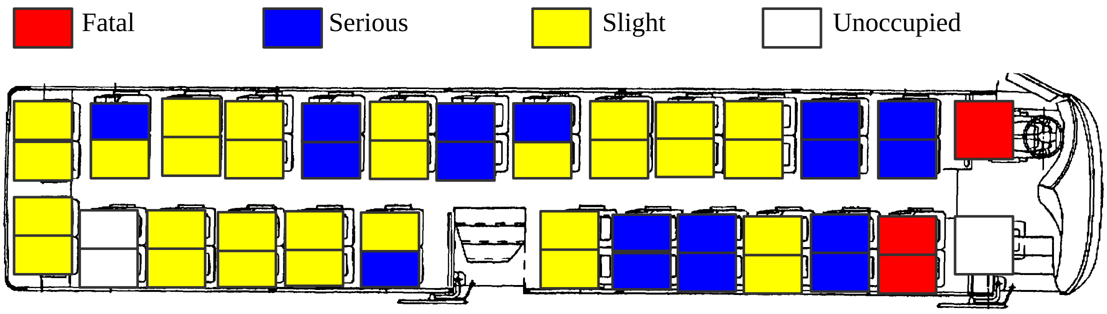


Figure 13. Severity of occupant injuries according to the police report.

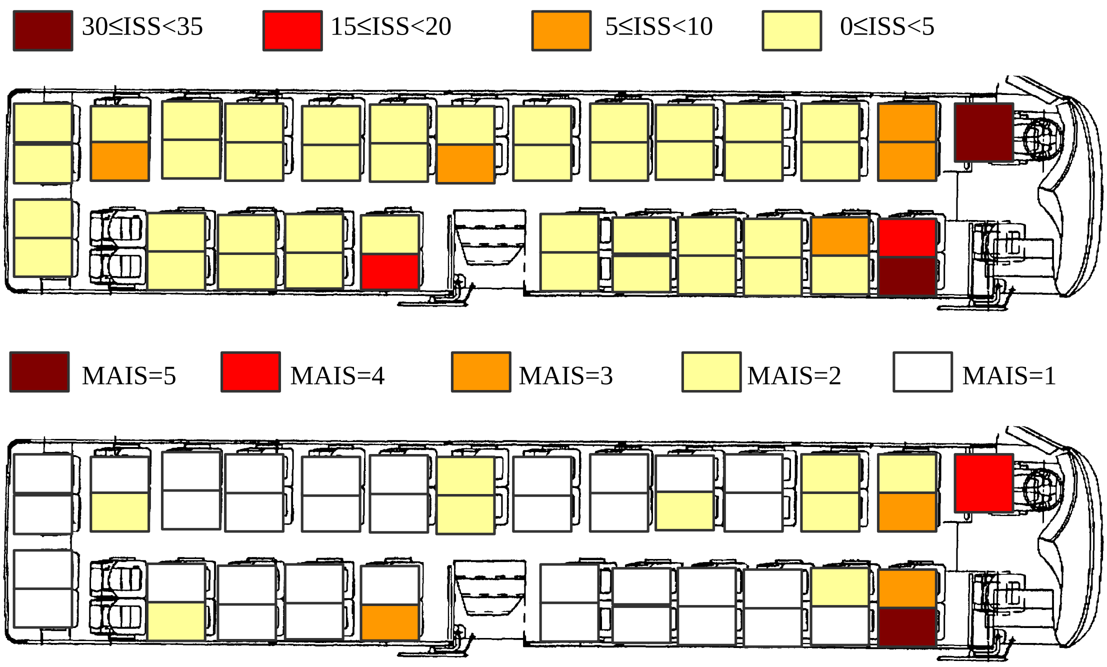


Figure 14. Severity of occupant injuries according to the classification scales.

No occupant was wearing a seat belt. Even the driver, whose position was equipped with a three-point safety belt, was unbelted at the moment of the accident. The seat for the guide was also equipped with a three-point belt but this position was unoccupied.
According to the requirements of the regulation ECE R-80.01, the retention of the passengers is left to the energy absorption properties of the seat backrests.

The positions selected for an in-depth analysis are marked in Figure 15. They are corresponding to two representative situations. The area no. 1 comprises the driver and the passengers just behind him. The area no. 2 considers the passengers behind the guide seat.

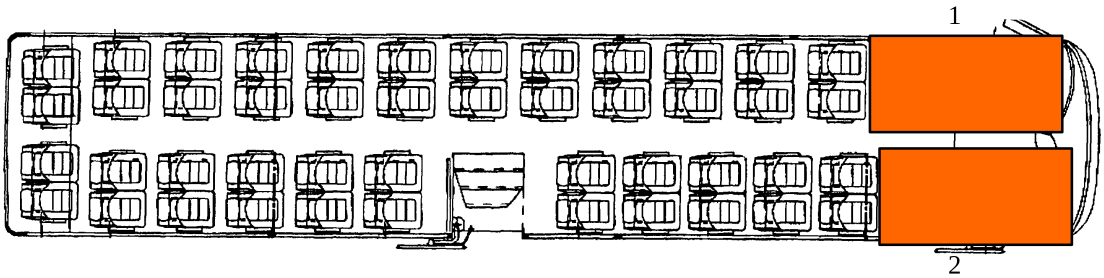


Figure 15. Areas selected for in-depth analysis.

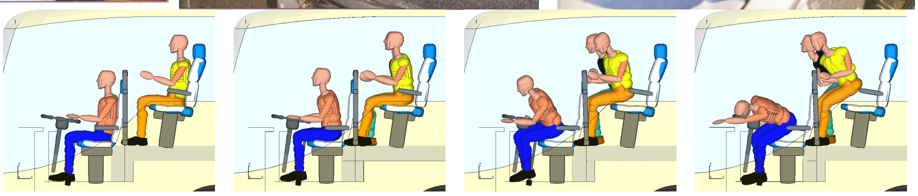
Occupant Simulation

The software used to simulate the occupant dynamics is MADYMO®. All occupants are the standard mathematical models of the dummy Hybrid III 50th percentile male.

A first simulation on the selected seating positions was made to compare with the real accident. In that case, the occupants were unrestrained. A second simulation was made with a three-point safety belt on each seating position. The properties of that seat belt were taken from an existing model of a bus seat.

In the area no.1, the survival space for the driver is reduced due to the deformation of the frontal part of the vehicle. The driver's legs hit the frontal interior parts of the vehicle. A head impact against the side structure and a chest impact against the steering wheel occur only in case of not wearing the seat belt. The cause of his death was a head trauma that could have been avoided using the seat belt. Photographs and simulation results are shown in Figure 16.

Without Seat Belts



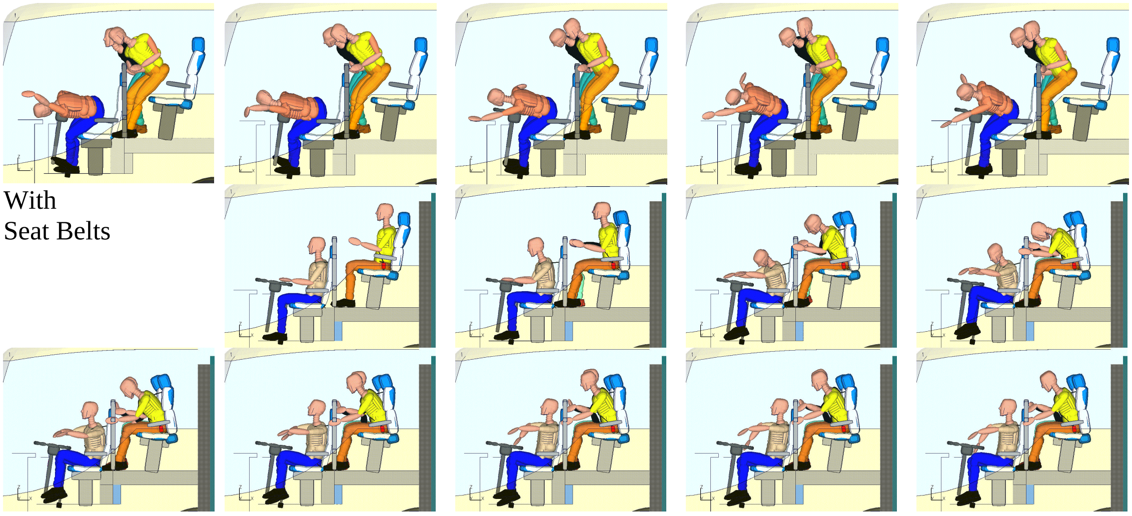
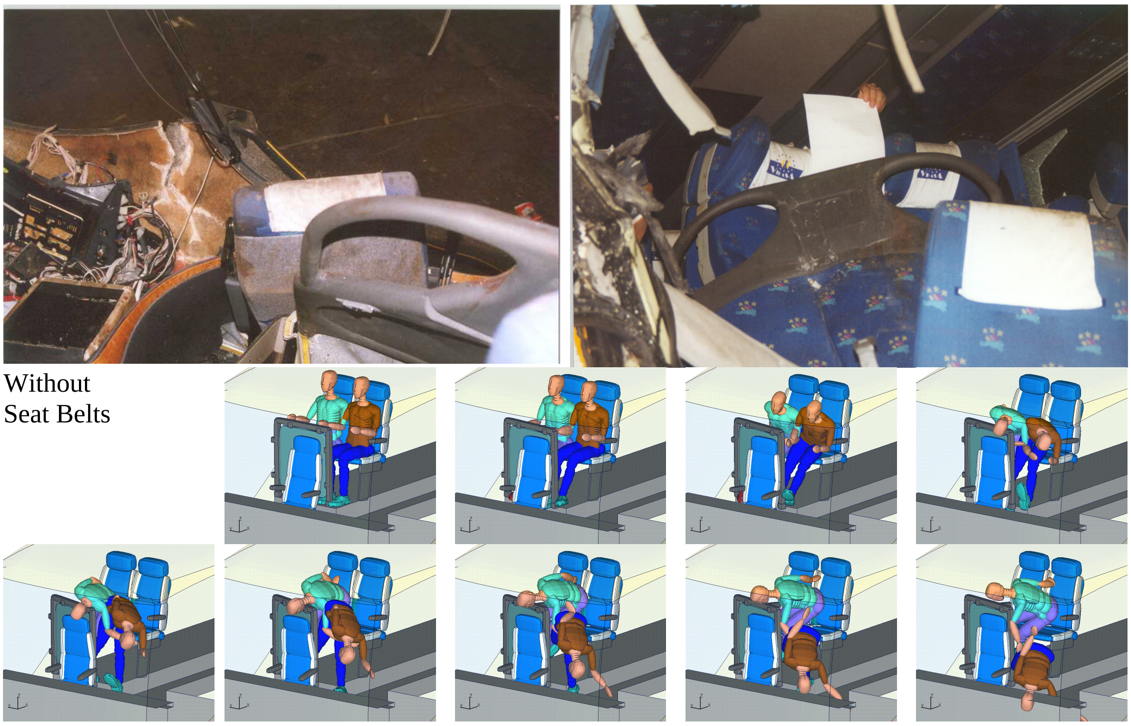


Figure 16. Photographs and MADYMO® animations for area no. 1.

The passengers behind the driver are ejected from their seating positions. The passenger on the left side is injured in the head due to an impact against the side structure of the vehicle and his legs hit the structure between him and the driver. The passenger on the right side suffers a serious injury in the upper part of the left femur, due to an impact against the structure in front of him. None of these injuries would be expected using a three-point seat belt.

In the area no. 2, the occupants move towards the corridor. Photographs and simulation results are shown in Figure 17. The total ejection of the left side passenger makes his head hit the floor. He died due to a head trauma and suffered multiple injuries in different parts of his body. The right side passenger died due to fatal injuries in the chest produced when hitting the structure between his position and the guide seat. None of these injuries would be expected using a three-point seat belt.



With
Seat Belts

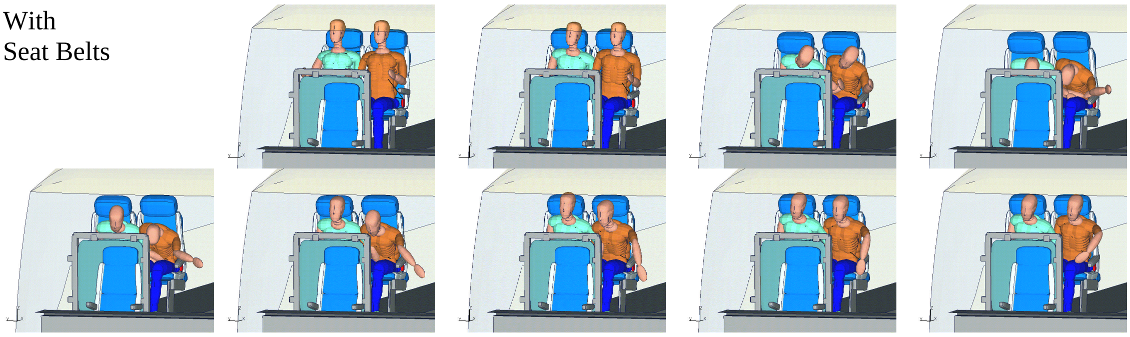


Figure 17. Photographs and MADYMO® animations for area no. 2.

CONCLUSIONS

The first case is a bus rollover accident without any collision against other vehicles. The ejection of the occupants is the fact that initiates the production of fatal injuries due to impacts. In this case, most of the passengers were drowned in a watercourse. It is clear that a three-point seat belt would avoid such ejection and reduce the risk of injuries.

The second case is a frontal collision with offset of a bus against a truck moving in the opposite direction. The direction of impulse is almost lateral. Passengers seating in those positions where a direct intrusion occurred could not have been saved by using a seat belt. But a three-point seat belt could have reduced the risk of injuries to all passengers seating at the right side of the vehicle. These were 18 people, 7 of them died and 11 were seriously injured. Again the ejection is the primary cause of serious and fatal injuries.

The third case is a fully frontal collision of a bus against a stationary rigid structure. The direction of the impulse is almost frontal. The velocity change during the impact is similar to the one specified by the regulation ECE R-80.01 for the approval of bus seats, but the energy absorption properties of the seat backrests are not always a sufficient guarantee to avoid injuries. A three-point seat belt would have reduced the risk of injuries in all of the seating positions, especially in those areas where the ejection of the passenger produced serious or fatal injuries. Once again, ejection is occurring. A three-point seat belt was available for the driver but he was not wearing it. It could have saved his life.

The responsibility of passive safety engineers is to recommend the compulsory use of three-point seat belts for adult passengers in coaches once it has proven to be efficient. Additionally, seat structures and anchorage systems need to be reinforced. The possibility of removing or changing the position of seat rows should not be allowed.

The adaptation of three-point seat belts to children requires specific solutions to be designed for school buses.

Travelling in buses is safe, but it could become even safer in the future. The next step in the enhancement of passive safety in buses is the future compulsory use of three-point seat belts for adult occupants.

ACKNOWLEDGEMENTS

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